MASTER OF SCIENCE
IN
APPLIED PHYSICS

TROPOSPHERIC EFFECTS ON UHF RADIO WAVE PROPAGATION AT LOW ELEVATION ANGLES

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The effects of low elevation angles on radio wave propagation are determined, specifically in application to geolocation. Currently, data received at low elevation angles, generally those angles less than about 10°, are of little use due to the impact of the troposphere, obstacle shielding, multipath, and other issues that are not completely resolved. An experiment was conducted from 23 October to 03 November 1995 to study the practicality of using low elevation angle data for precise geolocation. The objectives were to first define tropospheric and other low elevation angle effects on ultra high frequency (UHF) geolocation by means of an experiment and analysis. The second objective was to develop compensation techniques. This analysis establishes a minimum value of 1.6° for a usable elevation angle. This analysis also shows the error from tropospheric effects, quantified in the miss distance, experienced at low elevation angles. Comparisons with geolocation cases clarifies the extent of the remaining problem at low elevation angles. Use of the Hopfield tropospheric model is shown to be effective in most instances.

PARAMETRIC X-RADIATION FROM MOSAIC GRAPHITE: NEW RESULTS AND RECONCILIATION OF PREVIOUS EXPERIMENTS

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This thesis explores the effects of mosaic graphite on the yield of parametric x-radiation (PXR). PXR is the Bragg scattering of virtual photons associated with the Coulombic field of relativistically charged particles interacting with the atomic planes of a crystal. PXR was measured from three samples of mosaic graphite crystals with differing mosaicities. The number of photons per electron was calibrated with the fluorescent x-ray yield from a thin silver foil backing on each of the mosaic crystals. The detector angular field of view was narrowed from previous experiments. Improvements were made in the re-analysis of previous experiments by considering the thick target effects of the x-ray absorption. Previous experiments had erroneously assumed that the calibration fluorescent targets were thin. Re-analysis of previous data using corrections for solid angle, crystal absorption factors and effective thickness resulted in yields similar to those obtained in this work.

DEVELOPMENT OF A SURVIVABILITY AND LETHALITY ASSESSMENT CENTER (SLAC) AT NPS

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The purpose of this thesis is to develop a Survivability and Lethality Assessment Center (SLAC) at the Naval Postgraduate School. Students, faculty, and staff from many different curricula can use the SLAC for thesis research, for validating their own computer codes, and for classroom instruction. The models for the SLAC were obtained from the Survivability/Vulnerability Information Analysis Center (SURVIAC), Teledyne Brown Engineering, Menton, Inc. (for Grumman A/C Systems Advanced Programs), and from the Physics Department at the Naval Postgraduate School. Computer Systems in the SLAC include two SUN SPARC-10 Workstations, one Silicon Graphics Indigo, eight VAX6310 terminals with four graphics display consoles, eight IBM compatible computers, and two Macintosh computers. The SLAC now contains 24 models for running simulations. The SLAC is a comprehensive, user-friendly center for indi-

viduals or groups that need to use it. The security processing, computer account set-up, and documentation have all been streamlined to facilitate ease of use. Students, faculty, and staff should have no difficulty utilizing the SLAC.

AUTONOMOUS FRIENDLY-TARGET IDENTIFICATION AFTER WEAPONS RELEASE

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A new method for making friendly missiles avoid friendly targets is presented. Tagging friendly targets with a short range encrypted ultraviolet (UV) signature creates an information "bubble" that is unexploitable over long ranges. Selective photon detectors on missiles create a new identification friend-or-foe (IFF) process. This passive, autonomous IFF capability functions as the missile approaches friendly targets.

The UV signal originates from low pressure mercury lamps configured to radiate a strong, invisible, nearly monochromatic output (254nm). Modulation of optical output results from direct modulation of lamp power supply current. The already low visible emissions can be further suppressed with interference filters. 254nm wavelength light has atmospheric propagation characteristics suitable for this IFF application.

Photon detection is accomplished with solar-blind photomultiplier tubes. Bandpass optical filters block most solar and flame emissions while passing the 254nm modulated ultraviolet signal. Nighttime field tests using a 4.8 watt lamp support the assumed engagement scenario. This scenario analyzes a Mach 4 closure rate with a 30-G missile maneuver underway 2000 feet from the lamp resulting in disabling of proximity detonation and a 200 foot miss distance from the lamp.

CORRELATION OF EXPERIMENTAL AND FINITE ELEMENT MODAL ANALYSIS OF THE PHALANX M61A1 CLOSE-IN WEAPON SYSTEM

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The M61A1 galling gun is the principal component of the PHALANX Close-In Weapons System (CIWS), which provides U.S. Navy surface ships with a final defense against anti-ship cruise missiles. The objectives of this study are to provide an experimental set of modal parameters and to validate a new finite-element model (FEM) of the gun. Swept sine frequency response measurements on an actual PHALANX gun were conducted in the laboratory to obtain a complete set of modal parameters (frequency, amplitude, mode shapes). The finite-element model was correlated using the experimental modal frequencies as a reference. This result was obtained by adjusting stiffnesses in the three bearing assemblies within the gun: ball-bearing, needle bearing and ball joint. The investigation was conducted with and without the production muzzle restraint currently used in the fleet. Good agreement between the measured and computed FEM modal parameters was found for the first three modes in both the horizontal and vertical directions for the 5 to 125 Hz frequency range of interest. With the production muzzle restraint installed, agreement between the experimental and finite-element results was poor. It is suspected that "play" in the actual restraint mounting system is present, which is not modeled by the FEM. Recommendations are made for follow-on studies.

AN EXPERIMENTAL COMPARISON OF A PIN STACK TO A CONVENTIONAL STACK IN A THERMOACOUSTIC PRIME MOVER

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This thesis is an experimental comparison of a pin stack to a conventional rolled stack in a thermoacoustic prime mover. A thermoacoustic prime mover is a type of natural heat engine which converts a temperature gradient across a stack into acoustic energy. A pin stack uses wires which are arranged in a hexagonal array instead of the parallel or rolled plates of a conventional stack. The pin stack was constructed by threading 75 micron constantan wire between the hot and cold heat exchangers 2312 times. Computer modeling with the program DeltaE predicts that a pin stack will significantly improve the efficiency of the prime mover. In the experiment the temperature gradient across the stack was supplied by submerging the cold end in liquid nitrogen while holding the hot end at ambient temperature. The experiment was conducted for both the pin stack and a conventional rolled stack. The pin stack produced 20% higher acoustic pressures than the rolled stack and the efficiency was up to 31% better. The pin stack went into onset at a 41% lower mean pressure then the rolled stack.

DEVELOPMENT AND VALIDATION OF A SECOND GENERATION VISIBILITY-BASED MODEL FOR PREDICTING SUBJECTIVE AND OBJECTIVE MINIMUM RESOLVABLE TEMPERATURE DIFFERENCE PERFORMANCE FOR STARING THERMAL IMAGING SYSTEMS

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Several models have been proposed to predict the minimum resolvable temperature difference (MRTD) performance of second generation thermal imaging systems (TIS) which incorporate staring focal plane arrays. It has been suggested that these models are not accurate for predicting the performance of second generation staring focal plane arrays which have severe phasing or sampling characteristics not amenable to linear modulation transfer function analysis. A second problem with these models is that they require a particular set of assumptions concerning the observer eye/brain recognition process, which limits their usefulness in the prediction of the performance for systems that incorporate automatic target recognition (ATR) devices. In this thesis, a new model is presented for predicting the MRTD performance of second generation thermal imagers based on a minimum threshold input contrast, and a contrast reduction factor due to aliasing and blurring effects. The model makes no assumptions regarding the recognition process, which allows a separate threshold value to be defined for either a human or machine observer. The model incorporates aliasing concepts, and extends performance prediction beyond the nominal Nyquist rate of the system. The model's predictions are compared to the predictions of the current standard FLIR92 model and measured laboratory results for two different staring focal plane array imagers. In both cases, the model's predictions match measured results more closely than the predictions of FLIR92.

CORRELATION OF EXPERIMENTAL AND FINITE ELEMENT MODAL ANALYSIS OF THE PHALANX M61A1 CLOSE-IN WEAPON SYSTEM

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The M61Al galling gun is the principal component of the PHALANX Close-In Weapons System (CIWS), which provides U.S. Navy surface ships with a final defense against anti-ship cruise missiles. The objectives of this study are to provide an experimental set of modal parameters and to validate a new finite-element model (FEM) of the gun. Swept sine frequency response measurements on an actual PHALANX gun were conducted in the laboratory to obtain a complete set of modal parameters (frequency, amplitude, mode shapes). The finite-element model was correlated using the experimental modal frequencies as a reference. This result was obtained by adjusting stiffnesses in the three bearing assemblies within the gun: ball-bearing, needle bearing and ball joint. The investigation was conducted with and without the production muzzle restraint currently used in the fleet. Good agreement between the measured and computed FEM modal parameters was found for the first three modes in both the horizontal and vertical directions for the 5 to 125 Hz frequency range of interest. With the production muzzle restraint installed, agreement between the experimental and finite-element results was poor. It is suspected that “play” in the actual restraint mounting system is present, which is not modeled by the FEM. Recommendations are made for follow-on studies.

SPLIT-FIELD AND INTERNALLY FILTERED IMAGING POLARIMETER DEVELOPMENT AND TESTING

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A “split-field” infrared optical system has been designed and constructed to provide simultaneous image pairs in a single frame of an infrared (IR) imager, differing only in the direction of linear polarization. The optical train is afocal, allowing its use with a variety of infrared imaging devices. The system can operate in both long-wave IR (8-12 μm) and mid-wave IR (3-5 μm) with interchangeable polarizing splitter plates. Previous work at the Naval Academic Center for Infrared Technology (NACIT) at the Naval Postgraduate School has demonstrated that significant image improvement in infrared image contrast can be obtained by use of polarization filtering, especially for targets at sea through suppression of polarized sea background emission in the long wave, or of polarized reflection in the midwave. That work utilized digital subtraction of sequential image pairs with orthogonal polarizations, but suffered from inability to obtain simultaneous images and also from problems due to reflections from external polarization filters. Both of these problems are eliminated with the new split-field technique. Preliminary tests of this system with an AGA-780 imager were carried out in a field experiment using an Arleigh Burke DDG class ship as target at varying distances at sea. For comparison, images were also taken in successive pairs in time with the AGA-780 viewing the scene directly (without the split-field adjunct) with interchangeable internal polarizing filters in a rotatable filter wheel. Subjective and numerical analysis of the data from the field experiment demonstrated good image quality and contrast improvement, and potential for future utility.

MASTER OF SCIENCE IN APPLIED PHYSICS

DESIGN, DEVELOPMENT AND TESTING OF THE ALL-REFLECTION MICHELSON INTERFEROMETER FOR USE IN THE MID-ULTRAVIOLET REGION

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The development of the Naval Postgraduate School's high resolution All-Reflection Michelson Interferometer has progressed into the mid-ultraviolet region. Two separate Mercury light sources, a pen-ray lamp and a germicidal lamp, were used to evaluate the performance of the instrument for the 2537 Å emission. The interferometer uses a pinhole aperture at the focus of an off-axis parabolic mirror to obtain a collimated input beam. A plane sinusoidal diffraction grating divides the beam into two orders. Planar mirrors reflect the beams back to the grating where they are diffracted again such that both beams are now in the plane of the detector. The beams recombine to form a linear interference pattern which is recorded by an ultraviolet detector. Data-reduction software coherently adds the interference pattern matrix and creates a doubled-sided interferogram. The spectrum is obtained by using Fourier Transform techniques. This compact, lightweight and economically produced interferometer has no moving parts. For this reason, the All-Reflection Michelson Interferometer is well suited for remote sensing of mid- to extreme-ultraviolet ionospheric emissions from a sounding rocket, space shuttle or satellite platform.

A COST AND OPERATIONAL EFFECTIVENESS ANALYSIS FOR FUTURE ARTILLERY SYSTEM IN KOREA

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The goal of the defense acquisition program is finding the most effective system with the least cost. There are two key functions to achieve this goal: measuring the effectiveness and estimating the cost of each alternative. However, the acquisition procedure of a new weapon system is very complex and uncertain, because it involves anticipating the advantages and disadvantages both friendly and adversaries currently and/or in the future. Also estimating the Life Cycle Cost requires time and huge amount of data. The U.S. Department of Defense Instruction 5000 series was prepared to show how to avoid these complexities and uncertainties, known as a Cost and Operational Effectiveness Analysis (COEA).

The main purpose of this study is to show the COEA procedures and format by following the procedures specified in U.S. DoD Instruction 5000 series with an example of the future artillery system in Korea. As background, the concepts and terminologies of COEA and field artillery fire support are briefly examined. Following the format and procedures, the focus of this study is on the measures of the operational effectiveness of the field artillery system by using the computer simulation. The result of the simulation with different scenarios quantifies the performance characteristics and shows the relative effectiveness of each alternative.

The other parts are also explained briefly. The acquisition issues partly covers the inferiority of military balance between South and North Korea, and estimating costs for each alternative analyzed with a short example because of the lack of data and time limit. This thesis concludes with a summary of the results so that it discriminates and ranks each alternative.

AEROTHERMAL EFFECTS ON THE INFRARED SEEKER STARING SENSOR PERFORMANCE OF HIGH SUPERSONIC MISSILES

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The present work investigates the aerothermal effects on the electro-optical performance of a conceptual infrared seeker missile at Mach 4 at small angles of attack. Two window dome configurations are studied: an optical hemisphere and ellipsoidal shape window attached to a 3:1 ogive nose. A three dimensional thin-layer compressible flow solver is used to compute the flow field in front of the window and the window aerodynamic heating. A solution adaptive-grid scheme is applied to accurately compute the flow field and capture the bow shock. Noise-Equivalent-Temperature-Difference degradation due to "background" noise of the hot window is derived and computed for 3 levels of array non-uniformity for a range of mean dome temperatures covering the whole supersonic regime. Acquisition range for a staring sensor is estimated for several maritime scenarios modeled by LOWTRAN code. Background photon flux distribution on an array generated by the hot dome is computed using radiation transfer methods using the dome temperature field obtained by computational fluid dynamic methods. It is found that array non-uniformity has a strong influence on the seeker performance. This study indicates that the non-uniformity of the dome temperature has significant influence on the array fixed pattern noise induced by dome emission and so in the seeker detection and tracking ability.

EVALUATION OF EFFECTIVE MDTD/MRTD FOR FLIR FROM PREOS92 MEASUREMENT DATA

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This thesis addresses the evaluation of the apparent target-background temperature difference (ΔT_{app}) at maximum range and compares ΔT_{app} with MDTD/MRTD of a typical FLIR system. The atmospheric propagation code (SEARAD) and Planck's radiation law were employed to obtain atmospheric transmittance and path radiance. The atmospheric parameters were selected as close to the aircraft overflights as possible using PREOS 92 data as inputs of the SEARAD code. Ship target (R/V POINT SUR) modeling was established for MDTD/MRTD evaluation using a rectangular parallelepiped model of the ship's physical length, width and height. The geometry data for MDTD/MRTD evaluations were also selected from the PREOS 92 experiment measurement set. The MDTD/MRTD functions for a generic FLIR in wide field of view (WFOV) application were deduced from Shumaker. Johnson criterion was employed as a detection criterion. Resolution line-pairs at detection range to resolve the target have also been evaluated and compared against Johnson Criterion.

The temperature differences between ΔT_{app} and MDTD at detection range show large scatter, ranging from 5% to 600 %. They also show agreement with the same sensor altitude and viewing angle. A comparison of ΔT_{app} with MRTD at classification range and identification range show that using NFOV would be more appropriate for target classification/recognition. Resolution line-pairs at detection range derived from a typical WFOV MRTD curve show 10%~50% error for the eight runs, which is acceptable as compared against Johnson Criterion quoted as 1 ± 0.25 mRad.

THE VULNERABILITY OF AN AIRBORNE EARLY WARNING (AEW) SYSTEM AGAINST STAND-OFF NOISE JAMMING (SOJ)

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Based on the lessons learned from the Falkland War, an airborne early warning (AEW) system's importance is fully appreciated, and many countries field the AEW system to be a force multiplier for their air defense system. In this thesis, the AEW system's vulnerability, the sensitivity of each factor dominating the AEW system's detection range under hostile jamming, and the effect of stand-off noise jamming (SOJ) impacting the AEW system's detection range are evaluated using a simulation model to explore the AEW system's susceptibility and detection range degradation in a realistic combat environment.

HIGH-RESOLUTION RESIDUE ANTENNA ARCHITECTURES FOR WIDEBAND DIRECTION FINDING

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The performance of two novel interferometer antenna architectures for high-resolution, wideband direction finding are investigated. The first configuration incorporates a Symmetrical Number System (SNS) encoding of the interferometer amplitude response (symmetrical folding waveform). The second configuration incorporates a Residue Number System (RNS) encoding of the interferometer phase response (saw-tooth waveform). The residue architectures serve as a source for resolution enhancement in an interferometer array by decomposing the analog spatial filtering operation into a number of parallel sub-operations (moduli) that are of smaller computational complexity. Each sub-operation only requires a precision in accordance with the size of the modulus. A much higher resolution is achieved after the N moduli are used and the results of these low precision sub-operations are recombined. A four-element, 3 channel array using moduli set $m_1 = 3$, $m_2 = 4$ and $m_3 = 5$ was constructed in a ground plane using rectangular waveguide elements with a center frequency of 8.5 GHz. Experimental results are compared with the simulation results to demonstrate the advantages of this approach. The frequency response of the RNS array is investigated numerically. To correct the quantization errors due to any frequency offset, a fast correction algorithm is derived and is shown to have excellent results over a wide bandwidth.

DETECTION OF MINES USING HYPERSPECTRAL ANALYSIS

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This study focuses on the development of computer algorithms that can be used for automatic mine detection using hyperspectral imagery. These algorithms perform a pixel-by-pixel comparison of the scene spectra with the spectrum of a mine. The goal is to assign to every pixel a scale factor which gives the relative probability of finding a mine. Algorithms were tested on simulated data taken from the NPS Middle Ultraviolet Spectrograph (MUSTANG). Three computer methods are tested and relative results were compared. This analysis suggests that the potential exists to use

these methods in military applications. The ability to identify features in an image based solely on their spectral signature provides a new dimension to imagery interpretation.

SIMULATION OF DOUBLE BARRIER RESONANT TUNNELING DIODES

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The double barrier resonant tunneling diode (DBRTD) is one of several devices currently being considered by the semiconductor industry as a replacement for conventional very large scale integrated (VLSI) circuit technology when the latter reaches its currently perceived scaling limits. The DBRTD was one of the first and remains one of the most promising devices to exhibit a room temperature negative differential resistance (NDR); this nonlinear device characteristic has innovative circuit applications that will enable further downsizing. Due to the expense of fabricating such devices, however, it is necessary to extensively model them prior to fabrication and testing. Two techniques for modeling these devices are discussed, the Thomas-Fermi and Poisson-Schroedinger theories. The two techniques are then compared using a model currently under development by Texas Instruments, Incorporated.

ATMOSPHERIC PROPAGATION SIMULATIONS AND BOEING'S HIGH AVERAGE POWER FREE ELECTRON LASER

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The development of a high average power FEL for military applications, whether shipboard or not, represents a significant advancement in technology over present weapon systems design. The FEL has significant advantages over conventional kinetic systems and other classical high-energy laser systems. The rapid response, wavelength tunability, and infinite magazine make the FEL a highly desirable shipboard weapon system.

The initial part of this thesis examines the advantages of a FEL over a conventional kinetic weapon. Section II explores the atmospheric phenomena that affect the propagation of a laser beam enroute to its target. Section III presents the Boeing FEL proposal followed by the theory of the FEL. Last, in Sections V and VI, simulations are conducted to analyze the FEL's feasibility.

OPTICAL SYSTEM EVALUATION

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Optical and infrared sensors have an important role to play in modern military engagements, as the deployment of passive systems increases. To guarantee the efficient development and usage of such equipment, at a reasonable cost, a reliable and realistic simulation of sensor performance is fundamental. The research project presented in this thesis consists of two parts. First, basic software modules that characterize the target-detector radiative transfer problem were developed. This was accomplished by developing separate modules for each physical aspect of the problem. The second part concerned the viability of implementing the physics of such real-world radiative transfer effects into existing military simulation tools. The chosen simulation environment for this thesis was *NPS Platform Foundation*, an existing simulation software package that was developed at the Naval Postgraduate School.

MEASUREMENTS WITH WIRE MESH STACKS IN THERMOACOUSTIC PRIME MOVERS

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This thesis documents the first measurements of a thermoacoustic prime mover using wire mesh screens as the stack material. A thermoacoustic prime mover is a heat engine which converts thermal energy to sound. The stack material is sandwiched between the hot and cold heat exchanger and exchanges heat with the cycling gas elements flowing in the stack. The experimental stacks were constructed by inserting disks cut from wire mesh in a tube. In addition to simplicity, these stacks have two significant advantages. First, the wire is relatively impervious to moderately high temperatures and second, the effective thermal conductance of the structure is one to two orders of magnitude lower than a comparable metal "parallel plate" structure. Since no linear theoretical thermoacoustic models exist for these wire mesh stacks, the approach taken was simply to measure the performance of several different mesh stacks. Results gathered from two different prime movers indicate acoustic onset temperatures and amplitude performance comparable to the best data for parallel plate stacks. Moreover, measured efficiencies for mesh stacks appear to be substantially higher than for parallel plates.

QUANTITATIVE EVALUATION OF THE LIMITATIONS OF THE RADIATION BOUNDARY ELEMENTS IN THE FINITE ELEMENT CODE ATILA

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A quantitative evaluation of the limitations of the radiation boundary elements in the finite element code ATILA [Ref. 1] has been performed. Five three-dimensional models were employed, each representing a rigid spherical solid surrounded by water. Monopolar, dipolar and quadrupolar incident spherical waves were introduced and the corresponding scattered waves were computed using the ATILA code and an exact analytical solution.

The dimensionless parameters that characterize the problem are ka, kL, and kR where k is the wavenumber of sound in water, a is the radius of the scatterer, R is the outer fluid mesh radius, and L is the thickness of the fluid layer. The range of values investigated were kR=1.5, 2.5, 4.0, ka=0.5, 1.0, 2.0 and kL=0.5, 1.0.

For axially symmetric incident fields, the maximum normalized errors occurred at the poles and were 9%, 12%, and 6%, respectively. Furthermore, the errors for monopolar and dipolar incident fields were strongly influenced by the location of the radiation boundary (kR), less so by the scatterer's radius (ka); specifically, the error decreases with increasing kR and/or ka. The errors for quadrupolar incident fields do not exhibit any significant dependence on kR or ka. The errors for all the axially symmetric incident fields were not affected by variations of the element's size (kL). For non-axially symmetric incident fields, the maximum deviation occurred at the equatorial points and was less than 5.5%.

Further investigation using a two-dimensional model is proposed in order to determine the range of values of ka, kL, and kR which will result in negligibly small errors.

STEP FREQUENCY WAVEFORM DESIGN AND ANALYSIS USING THE AMBIGUITY FUNCTION

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This thesis investigates the use of the step frequency waveform, its design and analysis using the ambiguity function. The step frequency waveform consists of a series of N pulses each with a pulse width of τ, and whose frequency is increased from pulse to pulse in steps of Đf. A design procedure for detection of small targets with a surface (land or sea) based step frequency radar employing a high pulse repetition frequency (PRF) waveform is developed. The proposed method determines the waveform parameters for given radar specifications. A simple graphical implementation as well as a computer implementation are presented. The theoretical dimensions of the step frequency waveform are defined and verified for some waveforms with parameters similar to the waveform of interest. Finally, the ambiguity function is used to analyze the step frequency waveform.

NPS HIGH RESOLUTION SYNTHETIC APERTURE SONAR

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This thesis investigated the use of synthetic aperture techniques to achieve a long effective aperture, high resolution, imaging sonar. The approach included a full simulation of the system using the MATLAB programming environment that provided a model for developing six data processing algorithms and a working 25KHz, 1 m baseline, air medium synthetic aperture sonar. The six azimuthal processing techniques included: 1) a normal, real aperture, 2) an unfocused synthetic aperture, 3) a hybrid focused-unfocused system, 4) a fully focused one line algorithm, 5) a limited two-dimensional, fully focused algorithm and, 6) a limited two-dimensional, hybrid focused-unfocused algorithm. This thesis compared the run times, resolutions, and signal to noise ratios achieved by the six techniques both in simulation and experimental measurements collected with the actual prototype.